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RAPID POLYMER CONCRETE REPAIRS USING AVAILABLE FILLERS

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NOTICE

This technical report is approved for publication.

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Rapid Polymer Concrete Repairs Using Available Fillers

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Abstract

Monomers and resins used in the foundry industry are being investigated for use with locally available aggregates for making polymer concrete for rapid repairs of concrete pavements and runways. The polymer concrete has the ability of setting in a wide range of ambient temperatures and can be made with some moisture in the aggregate. Tests are being performed to determine curing times, flexural strengths and moduli of elasticity at different temperatures and times. Analyses of the repairs are being conducted to determine the stresses in the repairs using a wide range of assumed base and loading conditions. The results of the research will permit the thickness of the repair to be determined for the range of expected conditions.

Keywords: polymer concrete, repair, pavements, runways, analysis, aggregates.

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1. Introduction

The research was initiated with the objective of making rapid repairs of pavements and runways using locally available aggregates that are “less than ideal.” Monomers and resins that have proven very effective in the foundry industry as binders for sand molds are being used. A test program is underway to determine mechanical properties and curing time at different temperatures and for different moisture levels in the aggregates.

A structural analyses using pavement software is being conducted to determine the flexural stresses resulting from wheel loads of two different military aircraft applied at different locations on the repair. Different base conditions for the repair are being considered. Flexural stresses are determined for the different variables. From the testing program and analyses it will be possible to determine the required repair thickness for a wide range of conditions.

2. Materials

2.1. Monomers and Resins

Monomers and resins used in the foundry industry were selected for use. Six different mixtures were initially selected and reduced to three after initial testing.

2.1.1. PUB1 / PUB2 (aromatic polyurethane)

PUB1 and PUB2 were used in a 55:45 ratio based on weight. In addition to adding the resin to sand, a catalyst must be used with these polymers.

2.1.1.1. PUC1 and PUC2 (phenolic urethane catalyst)

Of the two catalysts to be used with this combination, PUC1 is the fastest. While PUC2 does slow the polymerization down, there is not a significant difference in the two catalysts. Both catalysts were used at a level of 1% based on weight.

2.1.2. AUB1 / AUB2 (aliphatic polyurethane)

The AUB1 was added to the sand first, and then the correct amount of AUB2 was added. These two components were added to the sand at a 1:1 ratio based on weight. AUB1 contains a built-in catalyst.

2.1.3. FB (furan no-bake binder)

The furan no-bake binder system consists of a reactive furan-type resin mixed with an acid catalyst. Extreme care must be taken so that the undiluted resin and catalyst do not come into contact with each since would result in a very violent reaction. The catalyst was mixed with the sand before adding the resin; 25% catalyst (based on binder weight) was used. FB was used with two different catalysts.

2.1.3.1. FC1 and FC2 (furan catalyst)

Many samples were mixed for testing using different ratios of resin to sand. The catalysts reacted similarly except for the time required for set. FC2 is the faster of the two catalysts.

2.1.4. SSB (sodium silicate)

Also known as waterglass, sodium silicate is an inorganic chemical made by combining various ratios of sand and soda ash at high temperatures. The catalyst, SSC, is used in the amount of 10 to 20% based on weight of SSB.

2.1.4.1. SSC (sodium silicate catalyst)
This material developed the least strength of all the polymers tested.

2.2. Aggregates
Several aggregates have been tested with these polymers. Initially, fine aggregate mortar bars have been tested; tests will be conducted using coarse aggregates. The different sands have different mineral compositions as well as grading. The results of sieve analysis tests (in accordance to ASTM C136) for the sands are provided in Figure 1. Before testing the material, the sand was dried in an oven at 101°C for at least 24 hours. For some tests, a specified amount of water was added to the dry aggregate.

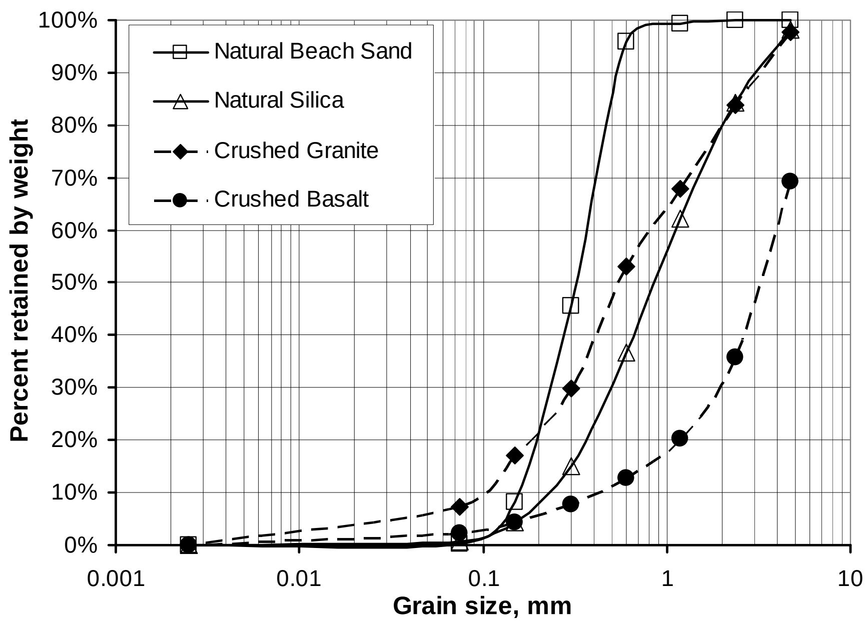


Figure 1. Sieve analysis results for sand

The methylene blue test was performed on the minus 75 µm portion of the sands to determine the amount of impurities in the aggregate. Higher values indicate more impurities. The methylene blue test is based on the AASHTO Designation TP57-99 [1]. Table 1 shows the results.

Table 1: Methylene blue test results

Sand	Reading	Value
Natural Beach Sand	1.0	0.5
Natural Silica	2.5	1.25
Crushed Granite	2.0	1.0
Crushed Basalt	3.0	1.5

3. Properties of Polymer Concrete

Tests were performed on polymer concrete made with different combinations of monomers/resins and sands in order to determine polymer properties.

3.1. Thermal Readouts

A data logger was used to determine the temperature of the mix time over time. Two mixtures were tested at one time. Thermocouples were inserted into the mixtures and readings were taken every one to three minutes beginning with the addition of the last mixture component.

A summary of the results is provided in Table 2. The peak time corresponds to the amount of time until the peak temperature was reached. Both SSB and FB were determined unworkable. SSB never set after 24 hours. FB both set too quickly and was difficult to work. Even before peak temperature was reached, the reactions were visibly exothermic.

Table 2. Summary of average peak time and temperature for initial set of polymer mortar sample

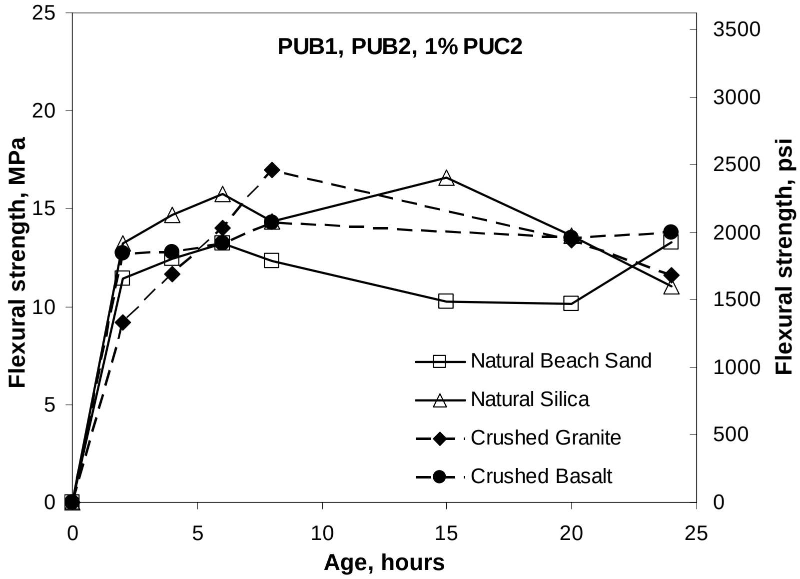
PUB1 / PUB2 w/ PUC1	15-20 min	30-50°C
PUB1 / PUB2 w/ PUC2	10-15 min	35-50°C
AUB1 / AUB2	10-15 min	50-60°C
SSB w/ SSC	0 min	20-25°C
FB w/ FC2	1-6 min	60-120°C
FB w/ FC1	25-30 min	65-80°C

3.2. Flexural Strength Testing

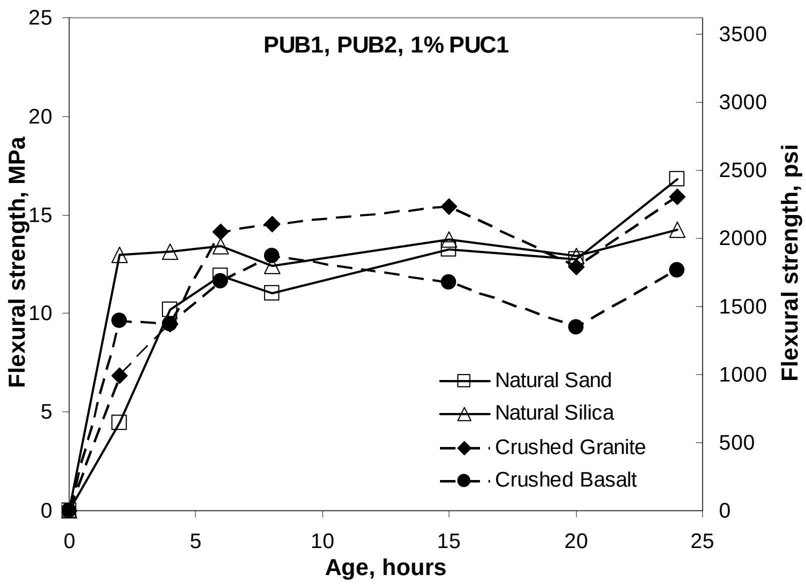
Beams 51 mm by 51 mm by 305 mm (2 in. by 2 in. by 12 in.) were cast from the resin/sand (1:4) mixtures using metal dual molds. The binder was mixed with the sand about one minute after adding the catalyst (last added). The mixture was transferred to the molds and finished.

The mixtures stayed in the molds until ±15 minutes before testing. Flexural tests occurred at 2, 4, 6, 15, 20, or 24 hours after the molds were filled. Figure 2 shows the strength with time. All mixtures are based on a 1:4 (polymer:sand) ratio. FB and SSB were eliminated test due to their performance in the previous tests.

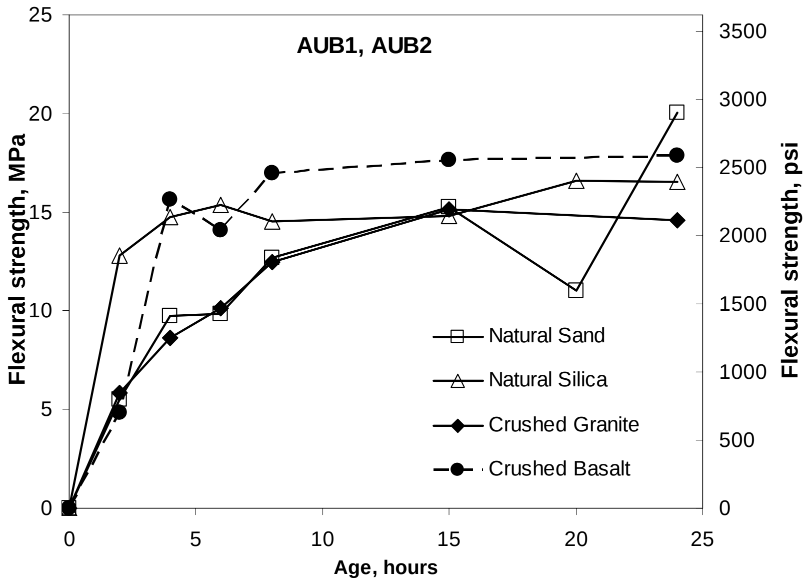
Third-point loading modulus of rupture testing was done in accordance with ASTM C78 [2]. Tests were performed using oven dry aggregates and with the addition of varied amounts of water added to the sand. Mix design 2 is represented in Figure 3 showing the effect of moisture on the mix.



(a) Mix Design A: PUB1, PUB2, 1% PUC2



(b) Mix Design B: PUB1, PUB2, 1% PUC1



(c) Mix Design C: AUB1, AUB2

Figure 2. Flexural test results

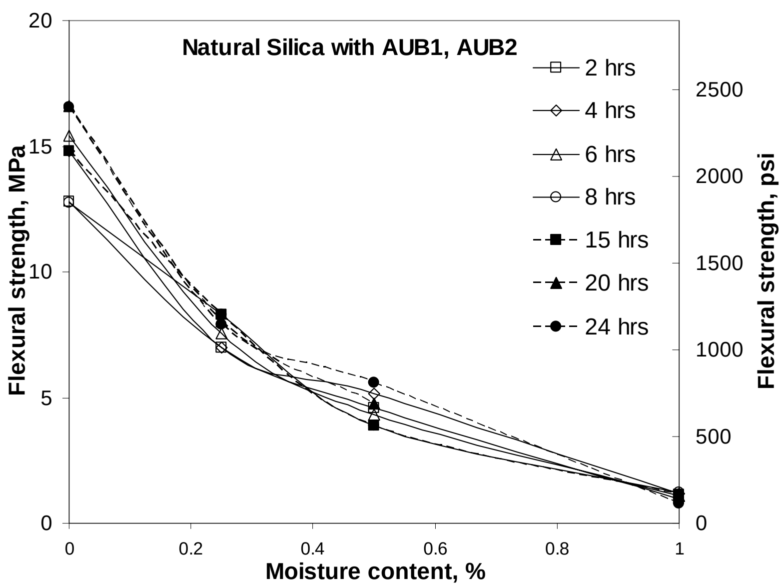


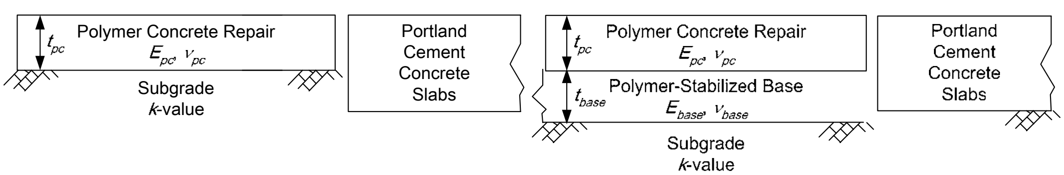
Figure 3. Flexural test results from Mix Design C with varying amounts of moisture

4. Stresses in Repair Due to Aircraft Loadings

The objective of this part of the study was to investigate the behavior of polymer concrete repairs of Portland cement concrete pavements (PCCP). The material properties of each layer, anticipated loading conditions, and desired quality of repair have to be determined or assumed before the stress analysis. Based on the stress analysis results, the criteria for the thickness for the polymer concrete repair considering significant variables are being developed. In this section, the polymer concrete-repaired pavement was modeled to calculate the maximum stress, and then sensitivity analyses for variables were performed.

4.1 Modeling of Polymer Concrete Repair

The maximum flexural stress at the bottom surface of the polymer concrete repairs was determined using a practical range of the material properties and loading conditions. A typical 7.32-m by 7.32-m (24-ft by 24-ft) polymer repair slab was selected for analysis. This size has been found to be adequate for the stress and deflection distribution for aircraft loading [3]. No load transfer between polymer repair and original PCCP was assumed, which represents the real field condition. The polymer-repaired slabs with a basic two-layer system (polymer concrete slab and subgrade) were considered first to determine the more sensitive variables. After the identification of the more sensitive variables of the two-layer system, the three-layer system (polymer concrete slab, polymer treated base and subgrade) was introduced to determine the critical loading position. The material properties of polymer concrete were assumed to be constant using typical values. The elastic modulus of polymer concrete (E_{pc}) was assumed to be 13.7 GPa (2000 ksi), while the Poisson's ratio (ν_{pc}) was assumed to be 0.25. Three variables were examined for the stress analysis: thickness of repair, subgrade reaction modulus, and loading locations. The thickness of the polymer concrete repairs ranged from 100 mm to 300 mm (4 in. to 12 in.), using 50-mm (2-in.) increments. Foundation (subgrade and base) properties are usually defined in terms of the modulus of subgrade reaction (k). In this study, k-values of 13.6, 27.1, 81.4, and 135.7 MPa/m (50, 100, 300, and 500 psi/in) were selected to represent the backfill with a minimum compaction, compacted natural subgrade, granular base, and cement stabilized base, respectively. Figure 4 shows the cross-section of the polymer concrete runway repair.

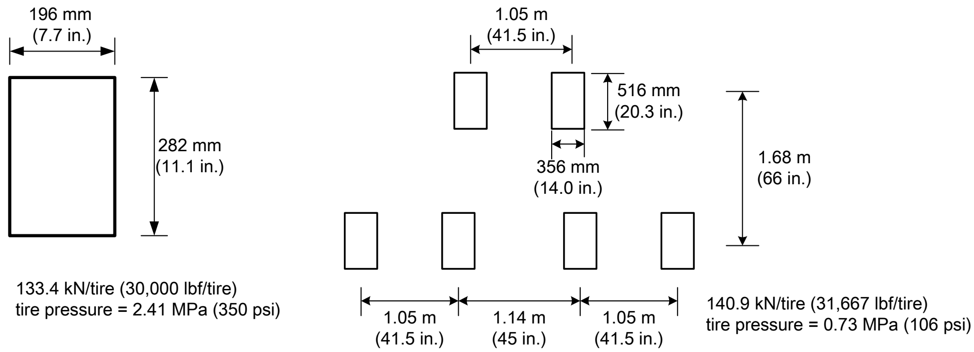


(a) Two-layer system (b) Three-layer system

Figure 4. Cross-section of the polymer concrete repair

The EverFE [4, 5] rigid pavement analysis software was used for the calculation of the maximum stress values of the polymer concrete slabs using two designated aircraft loading types: F-15 and C-5, the representative users of the facilities. The F-15 aircraft has two single-tire cartload main gears while the C-5 main gears consist of four six-tire cartloads. Because of the relatively large

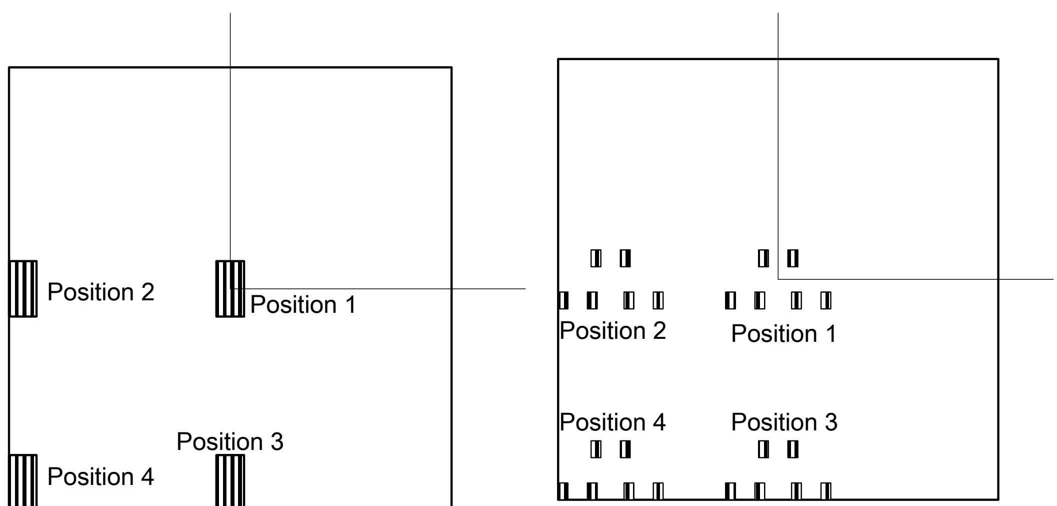
cartload spacings, the calculated maximum stress was not influenced by an adjacent cartload. The stresses presented in this paper are the results of analyses on a single loading cart for both F-15 and C-5. For FEM analysis, the tire contact areas were converted to equivalent tire contact area using the PCA method [6]. The footprint of a single loading cart for each aircraft is shown in Figure 5.



(a) F-15 loading cart (b) C-5 loading cart

Figure 5. Footprint of single cartload for stress analysis

To investigate the effect of loading position, the single cartloads from each aircraft type were applied at four different loading positions as shown in Figure 6.



(a) F-15 aircraft (b) C-5 aircraft

Figure 6. Vertical gear positions for stress analysis

4.2 Sensitivity Analysis Results

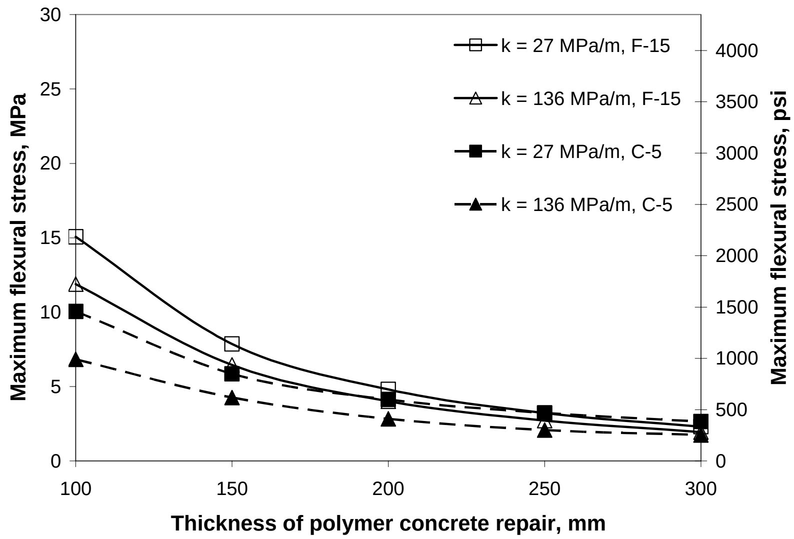
A large range of conditions for variables was originally considered during the sensitivity analysis process. As the study progressed, the stress analyses were focused on the obviously sensitive variables, which have a significant effect on the maximum flexural stress values. The considered factors are discussed briefly based on the findings presented in the following paragraph.

The selected stress analysis results for the two-layer systems are presented in Figure 7. The loading position was the most sensitive factor for the maximum stress. The long-side edge loading (load position 2 in Figure 6) showed the highest flexural stresses, and the interior loading conditions showed the lowest values. The subgrade reaction modulus (*k*-value) was found to be another important factor as shown in Figure 7. The subgrade stiffness is one of the key factors of repair of a damaged PCCP with two-layer system. In general, the F-15 aircraft loadings produced higher maximum stress values than those of the C-5 for both interior and edge loading conditions. In summary, the F-15 edge loading condition was found to be the most severe loading case.

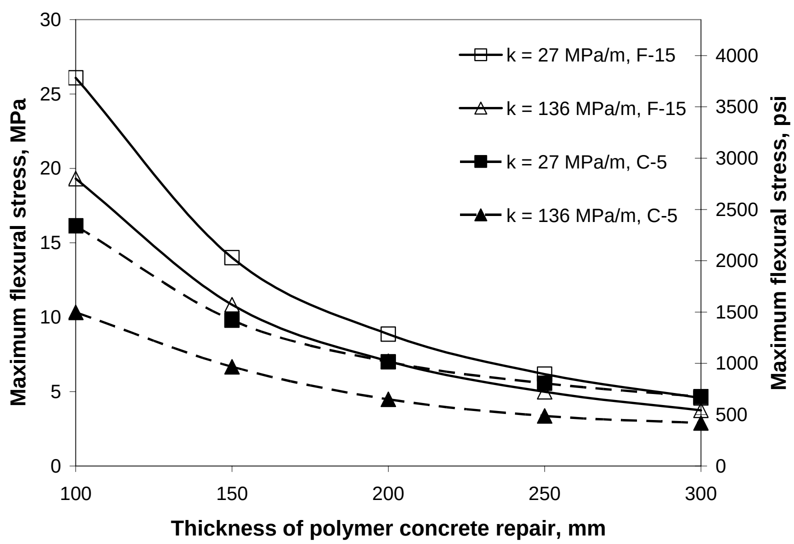
The three-layer system maximum stress calculation results for the F-15 aircraft loading are illustrated in Figure 8. Typical material properties for polymer-stabilized base were assumed. The elastic modulus of polymer-stabilized base (E_{base}) was assumed to be 3.5 GPa (500 ksi), while Poisson's ratio of polymer concrete repair (v_{pc}) was assumed to be 0.20. The application of the polymer-stabilized base has great impact on the magnitude of the maximum flexural stress. Even minimal use of the polymer-stabilized base is helpful in reducing the stress in the repair. In addition, the effect of subgrade modulus (*k*-value) on maximum stress significantly decreased with a slight increase of the thickness of polymer-stabilized base. In other words, the application of the polymer-stabilized base can significantly reduce the sensitivity of *k*-value for the maximum flexural stress.

5. Conclusions

Polymer concrete was made using a variety of sands and resins. Flexural strengths of 10 to 20 MPa were obtained in a few hours after casting. Curing times and strengths are adequate for repair materials. Tests using moisture in the aggregate show that flexural strengths are reduced by 40 to 50% for moisture contents of 0.25%, but strengths are still adequate for use as a repair material. The pavement analysis indicated that the most critical location for the wheel loads is at the exterior edge. Required thicknesses were determined for a wide range of variables: repair thickness and modulus, subgrade stiffness, and polymer-stabilized base thickness and stiffness. Two support scenarios were investigated: repair over an unbound aggregate subgrade and repair over a polymer-stabilized base placed over an unbound subgrade.

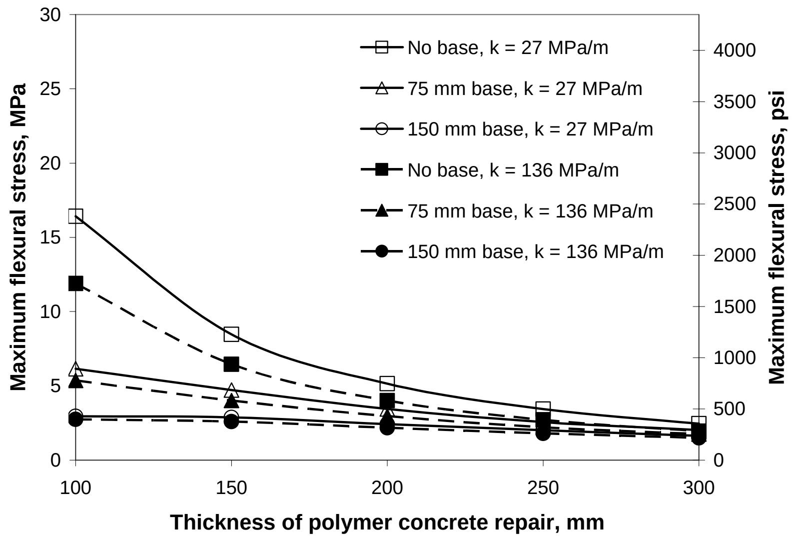


(a) Interior loading position

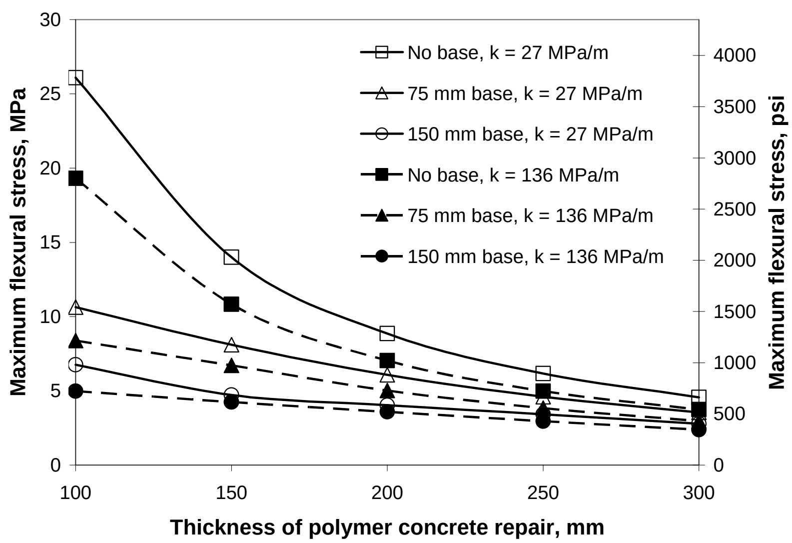


(b) Edge loading position

Figure 7. Stress analysis results for two-layer system



(a) Interior loading



(b) Edge loading

Figure 8. Comparison of the maximum flexural stress due to the F-15 aircraft between two-layer and three-layer systems

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